SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

Analysis Plan for Evaluation of Culebra Water-Level-Rise Scenarios

AP-110

Task Number 1.4.1.1

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1. Introduction

This Analysis Plan directs the evaluation of scenarios proposed to explain observed rising water levels in the Culebra Dolomite Member of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) site. The Culebra flow model used in performance assessment (PA) calculations for the WIPP Compliance Certification Application (CCA; DOE, 1996) was calibrated to heads assumed to represent steady-state conditions as well as to transient heads arising from hydraulic testing and shaft activities. In the assessment of compliance monitoring parameters (COMP's) for the year 2000 (SNL, 2001), freshwater heads were compared to trigger value ranges established for 28 of the 32 wells (Figure 1) used in generation of the CCA Culebra transmissivity (T) fields (water levels in the other four wells could not be determined because the wells had been removed from the monitoring network, i.e., plugged and abandoned, or converted to monitor units other than the Culebra). Of these 28 measurements, freshwater heads in 21 wells appeared to be outside the trigger value ranges, 20 higher and one lower than expected. Head changes in four of the wells could be explained by problems with well casings and/or leaking packers, leaving 17 wells with unexpectedly high freshwater heads. Exceeding trigger values does not mean that continued compliance is in jeopardy, but that further action must be taken to evaluate the cause(s) and consequences of exceeding the trigger value.

Based on requirements for further investigations when trigger values are exceeded and concerns expressed by the Environmental Protection Agency (EPA, 2002) and Environmental Evaluation Group (EEG, 2002), investigative studies have been defined to explain the water-level changes (SNL, 2003). The modeling activities to be performed are described in this plan.

The scenarios to be evaluated involve: (1) leakage into the Culebra of refining process water discharged onto potash tailings piles, probably through subsidence-induced fractures and/or leaky boreholes; (2) leakage into the Culebra of water from units above the Culebra (Magenta and/or Dewey Lake) or below the Culebra (e.g., Salado, Bell Canyon) through poorly plugged and abandoned boreholes; and (3) leakage into the Culebra of water being injected at depth (e.g., into the Bell Canyon Formation) through leaky boreholes.

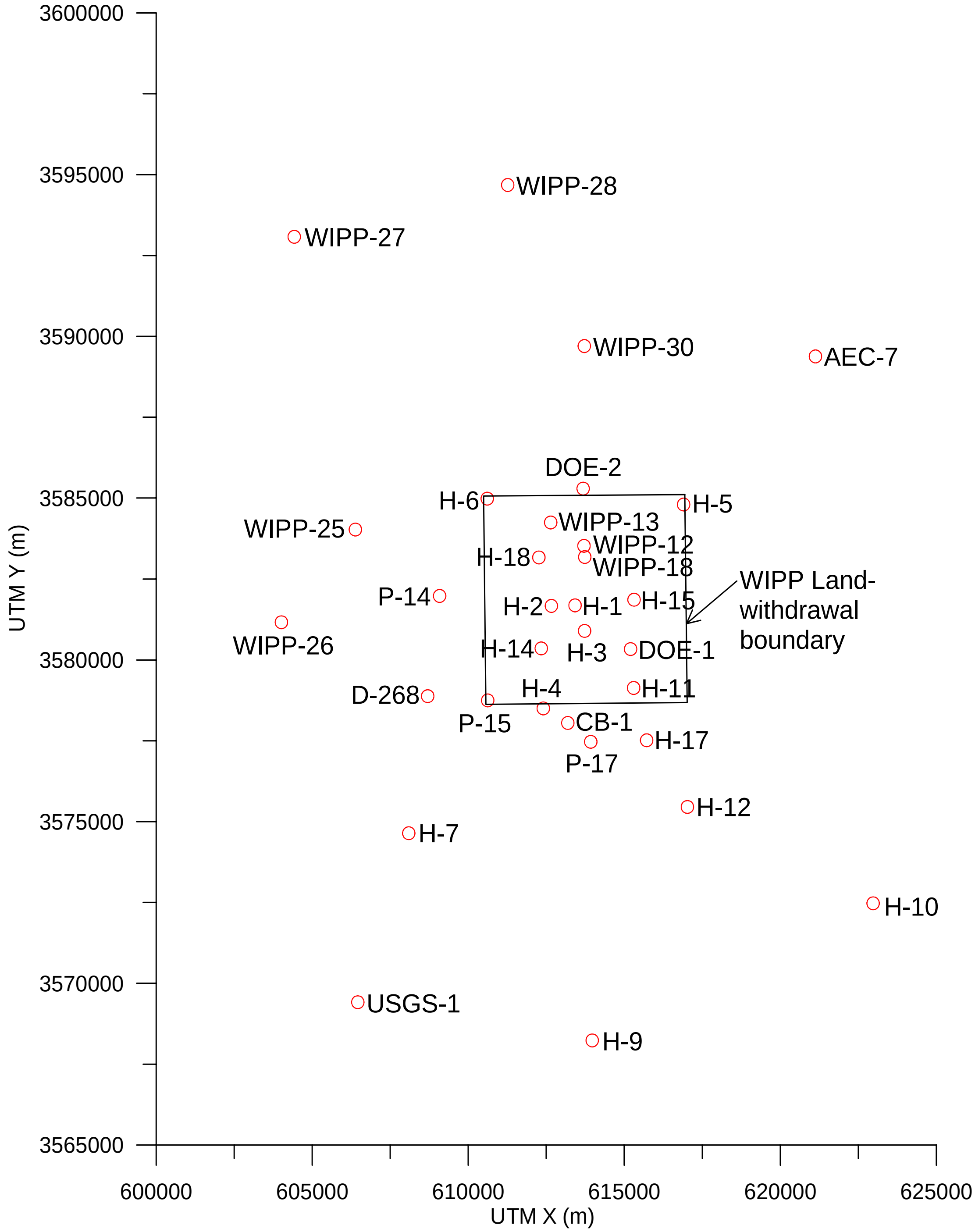

Figure 1. Locations of Culebra wells used in CCA modeling.

The scenarios will be evaluated using **MODFLOW-2000** (Harbaugh et al., 2000) and T fields developed for the WIPP Compliance Recertification Application (CRA) under Analysis Plan AP-088 (Beauheim, 2002). **MODFLOW-2000** will be used to simulate the effects of various amounts of leakage applied to the Culebra at known tailings pile and/or borehole locations on groundwater levels thoughout the model domain. The simulated responses at observation well locations will be compared to the hydrographs of water levels at those wells collected under WIPP monitoring programs.

The modeling results are intended to demonstrate which, if any, of the hypothesized scenarios are the likely explanation for the observed water-level changes, and to estimate the effects on Culebra hydrology of those scenarios continuing in the future. The information developed under this Analysis Plan may be used for Compliance and/or Programmatic Decisions.

2. Observed Water-Level Changes and Potential Causes

Water-level records (hydrographs) from the WIPP wells reveal a variety of changes since monitoring began in the earliest wells in 1977. Hydrographs from the wells within the 16 square miles of the WIPP site typically show myriad effects because of the extensive well testing and shaft activities that occurred in the 1980's. Hydrographs from wells in Nash Draw and P-14 typically do not show responses to tests conducted on the WIPP site, but nevertheless show broad rising and falling trends over periods of several years (Figure 2). Since 1989, a general long-term rise has been observed in both Culebra and Magenta water levels (e.g., Figure 3) over a broad area including Nash Draw. At the time of the CCA, this long-term rise was recognized, but was thought (outside of Nash Draw) to represent the recovery from the accumulation of tests and shaft leakage that had occurred at the WIPP site since the late 1970's. Changes in the amounts of potash mill effluent discharged onto tailings piles in or near to Nash Draw were considered the likely cause of water-level changes observed in wells in Nash Draw (e.g., Silva, 1996), but not at wells outside the draw. As the rise in water levels has continued over recent years, however, observed heads have exceeded the ranges of uncertainty established for the steady-state heads in most of the 32 wells used in calibration of the T fields for the CCA, throwing into question the hypothesized explanations for the changes. In addition, short-term fluctuations of unknown origin in Culebra water levels have occurred in specific areas (e.g., Figure 4).

In addition to the water-level changes discussed above, significant water-level fluctuations have also been observed in the Culebra at H-9 south of the WIPP site (Figure 5). These changes have propagated to the north to wells near the southern WIPP site boundary such as P-17 and H-12. Because of the presence of salt-water-disposal and injection wells several miles northeast of H-9 and extensive oil and gas drilling around H-9, speculation as to the cause of the water-level changes has centered on leaking boreholes (Silva, 1996). The target horizon for salt-water-disposal wells lies in the Bell Canyon or deeper formations. For water being injected at those depths to be influencing Rustler aquifers, it would have to be leaking either around the casing in the injection wells themselves or through other wells, perhaps improperly plugged and abandoned, that penetrate the injection horizon.

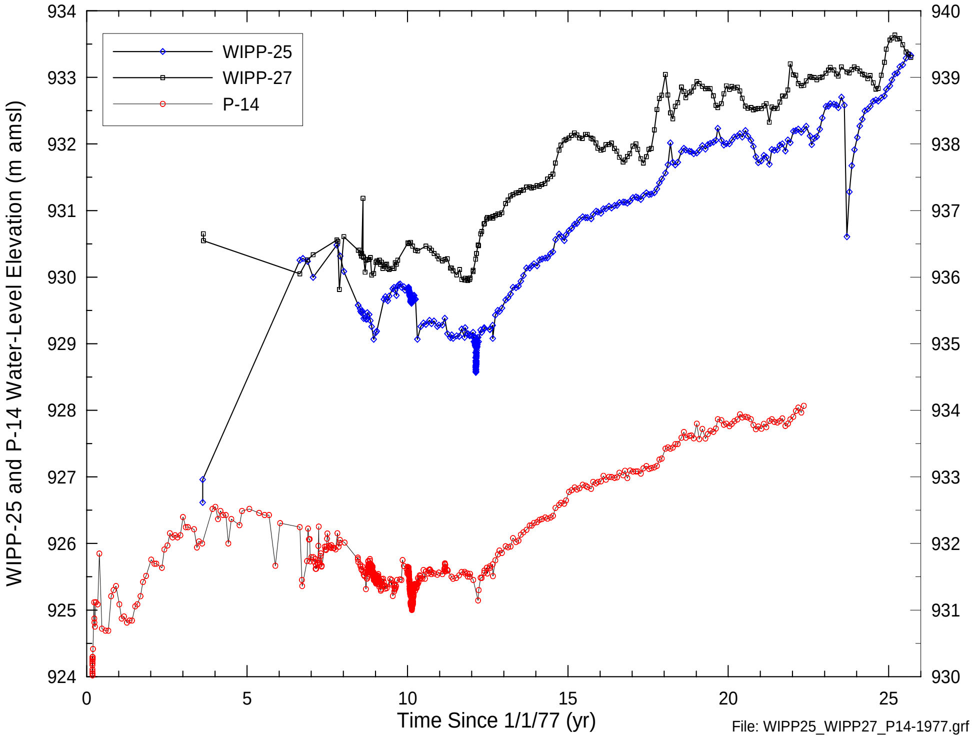

Figure 2. Water-level trends in Nash Draw wells and P-14.

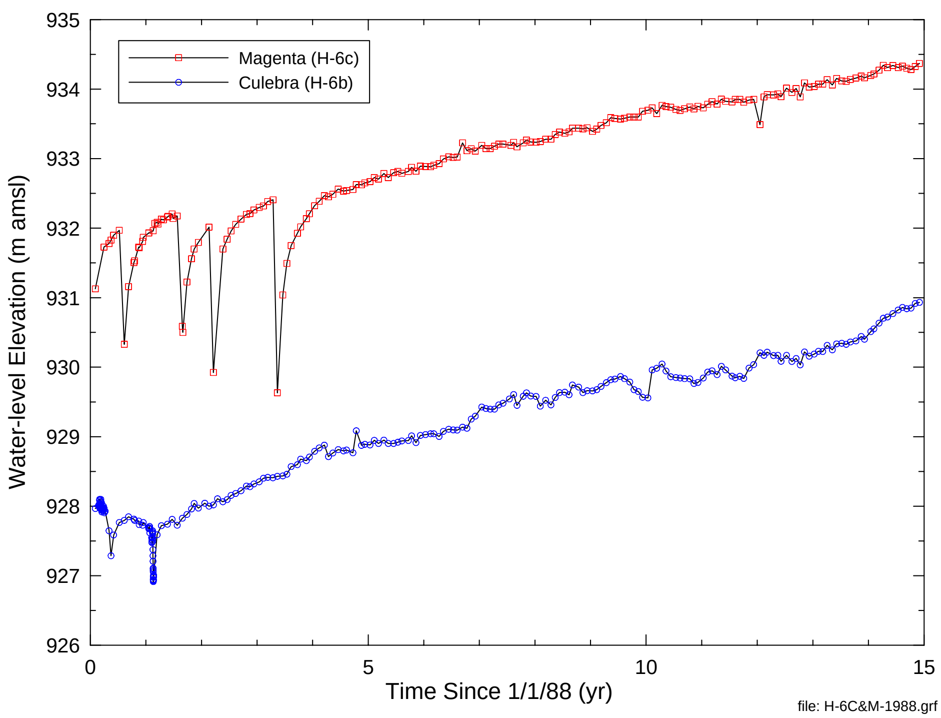

Figure 3. Rising Culebra and Magenta water levels at H-6.

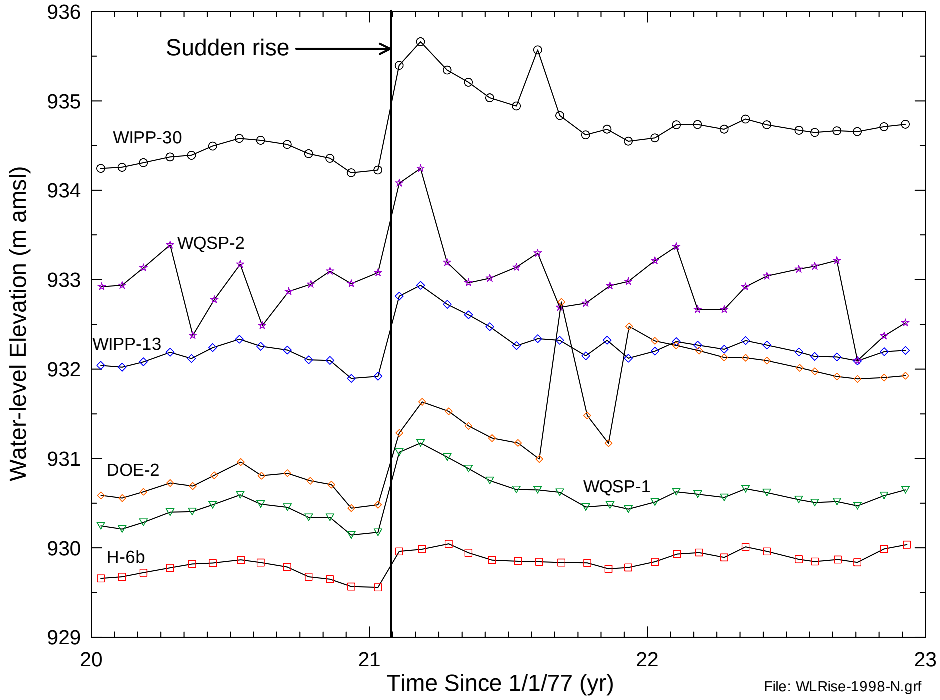

Figure 4. Example of short-term water-level fluctuation north of WIPP.

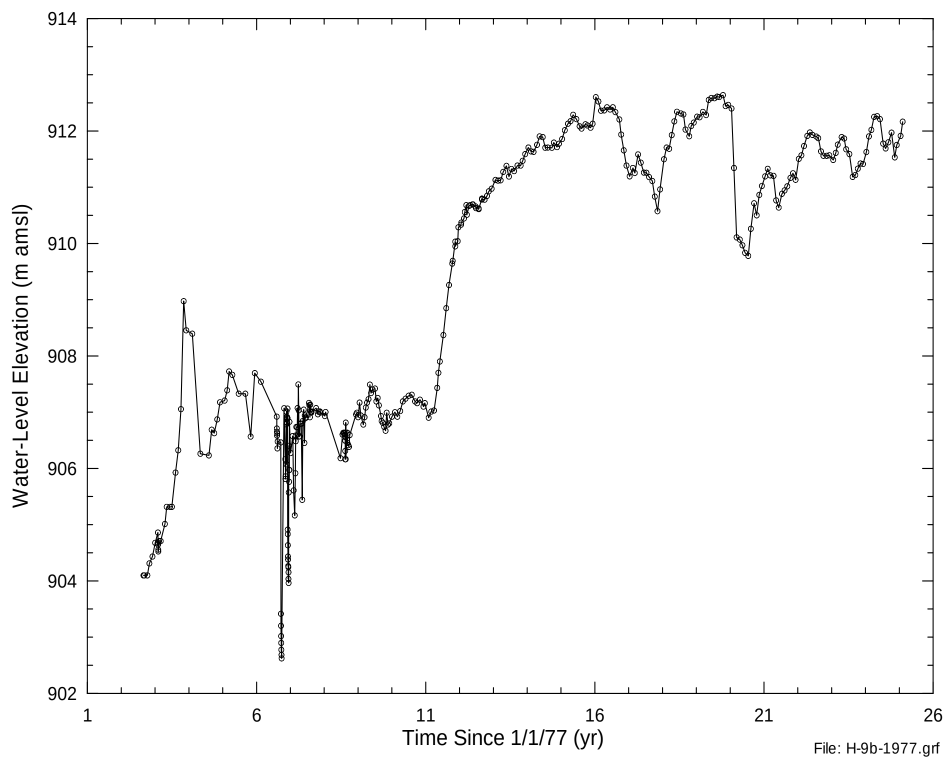

Figure 5. Culebra water levels at H-9.

Other possible explanations for observed water-level changes center on potash and oil and gas exploration holes. Potash exploration holes are used to evaluate potash resources in the upper Salado, and are typically plugged and abandoned shortly after drilling. Oil and gas exploration holes target horizons below the Salado, and may be plugged and abandoned shortly after drilling if found to be dry, or decades later at the end of their productive lives. Some of these holes date back to the first half of the twentieth century, when plugging and abandonment requirements and practices were not as rigorous as they are today. Exploration holes that were not plugged through the Culebra with cement provide potential avenues for vertical hydraulic communication among the formations above and/or below the Salado.

Based on the information discussed above, three scenarios have been defined that are thought to have the potential to affect water levels and are considered worth investigating further:

1. Leakage from tailings piles/ponds causing locally elevated Culebra (and Magenta) heads, which then propagate through the system;

2. Leakage through boreholes that are poorly cased or incompletely plugged and abandoned, including leakage from units both above and below the Culebra;

3. Leakage from wells injecting into the Bell Canyon or deeper formations (either directly from the injection well into the Culebra or through a nearby well).

Note that these scenarios are not mutually exclusive, and may all be contributing to the observed water-level fluctuations.

3. Information Sources and Tools

Modeling of the scenarios that have been proposed to explain observed water-level rises requires different types of data from various sources. The types of data required and the sources for each are discussed below.

3.1 Water Levels

Observed water levels in Culebra wells provide both the motivation for this study and the basic data to which the modeling results will be compared. Culebra water levels have been measured and reported by a number of different organizations since well installation for the WIPP project began. Data collected by the U.S. Geological Survey (USGS) have been reported by Mercer and Orr (1979) and Richey (1986; 1987a,b). Data collected by or on behalf of Sandia National Laboratories are reported in Hydro Geo Chem (1985), Intera Technologies and Hydro Geo Chem (1985), Intera Technologies (1986), Saulnier et al. (1987), and Stensrud et al. (1987; 1988a,b; 1990). Data collected by the WIPP Management and Operating Contractor (MOC), now known as Washington TRU Solutions (WTS), are reported in Kehrman (2002a).

3.2 Discharge onto Tailings Piles

The Mississippi East tailings pile located 10 to 12 km due north of the WIPP site (Figure 6) is the tailings pile most likely to be affecting water levels north of and on the WIPP site. Disposal of mine tailings and refining-process effluent at that location began in 1965. Records obtained from the New Mexico State Engineer show how much water has been pumped from local aquifers (Ogallala or Capitan) each year since 1973 for use in the potash-refining process (Figure 7). Since 1973, an average of 2400 acre-feet of water per year has been pumped. Geohydrology Associates (1978) estimated that approximately 90% of this water is discharged onto the tailings pile, and that approximately half of the brine discharged seeps into the ground annually, while the remainder evaporates. Therefore, on average, approximately 1100 acre-ft of brine may be infiltrating each year. Brine from this tailings pile may enter the Rustler through leaky boreholes and/or by first moving laterally into Nash Draw and then downward through subsidence fractures that have opened over potash mine workings (Figure 8).

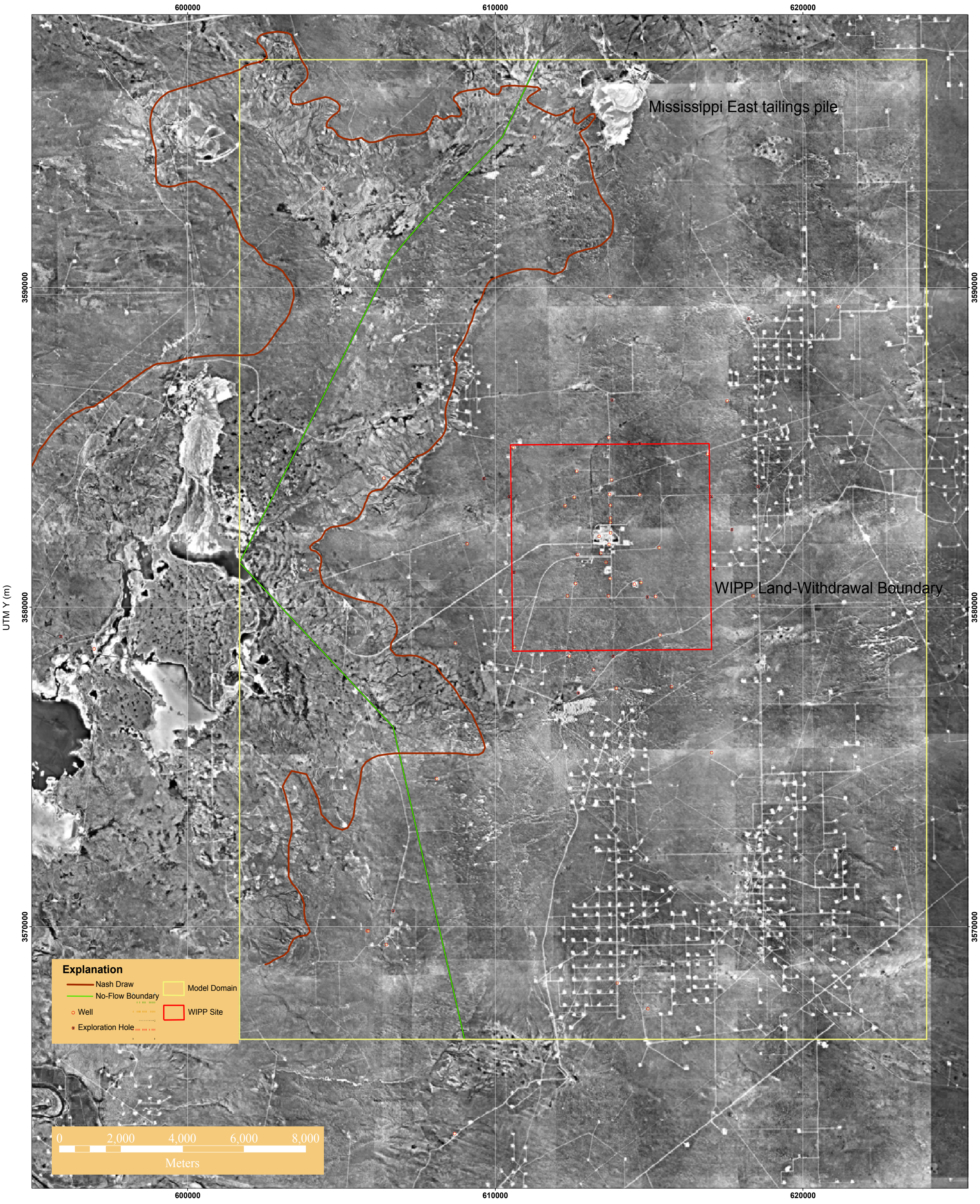

Figure 6. Airphoto map of WIPP site (red square) and surrounding area.

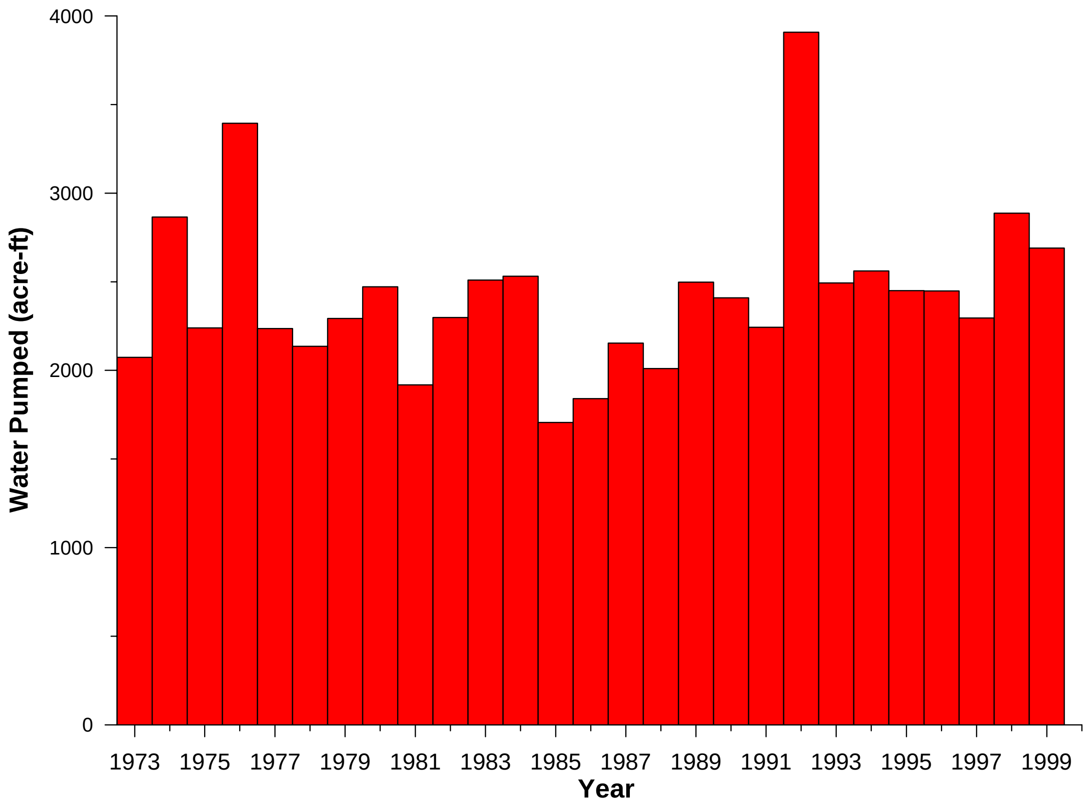

Figure 7. Annual water pumpage at Mississippi East potash mill location. Data source: New Mexico Office of the State Engineer

3.3 Plugged and Abandoned Boreholes

The potash exploration holes shown in blue on Figure 9 are used to evaluate potash resources in the upper Salado, and are typically plugged and abandoned shortly after drilling. Some of these holes date back to the first half of the twentieth century, when plugging and abandonment practices were not as rigorous as they are today. From a search of BLM records assembled for Washington Regulatory and Environmental Services (WRES) for the Delaware Basin Drilling Surveillance Program, plugging and abandonment records were found for 576 exploration holes in the vicinity of the WIPP site (T20-24S, R30-32E). Figure 10 shows the locations of 84 of these holes that were not filled with cement to the ground surface, but were instead filled over some interval(s) with mud, sand, cuttings, salt cuttings, and/or brine, or were simply left open. These holes provide potential avenues for vertical hydraulic communication among the formations above the Salado. Many of the incompletely plugged potash holes are located near, and in some cases beneath, the Mississippi East tailings pile.

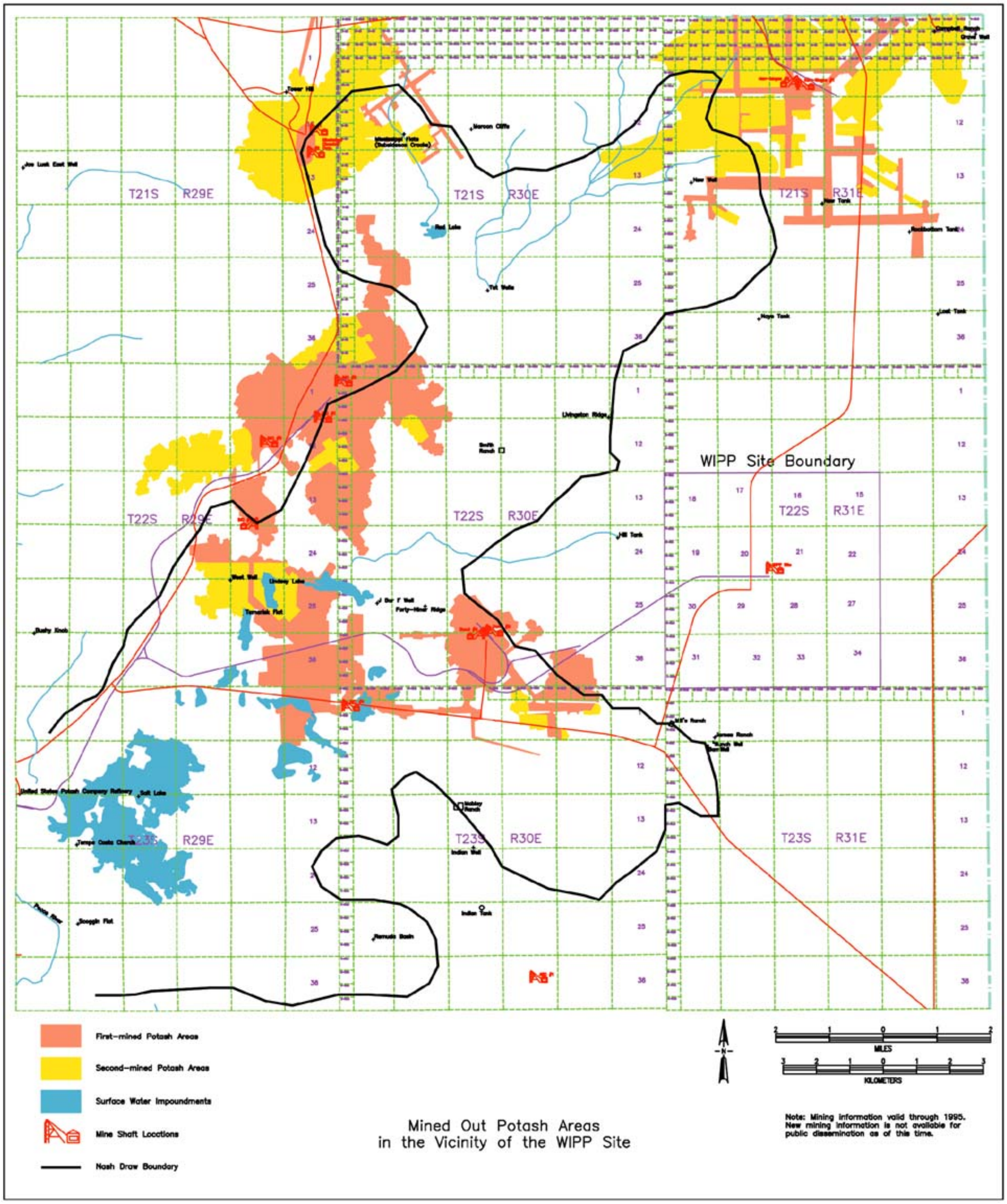

Figure 8. Mined areas in Nash Draw.

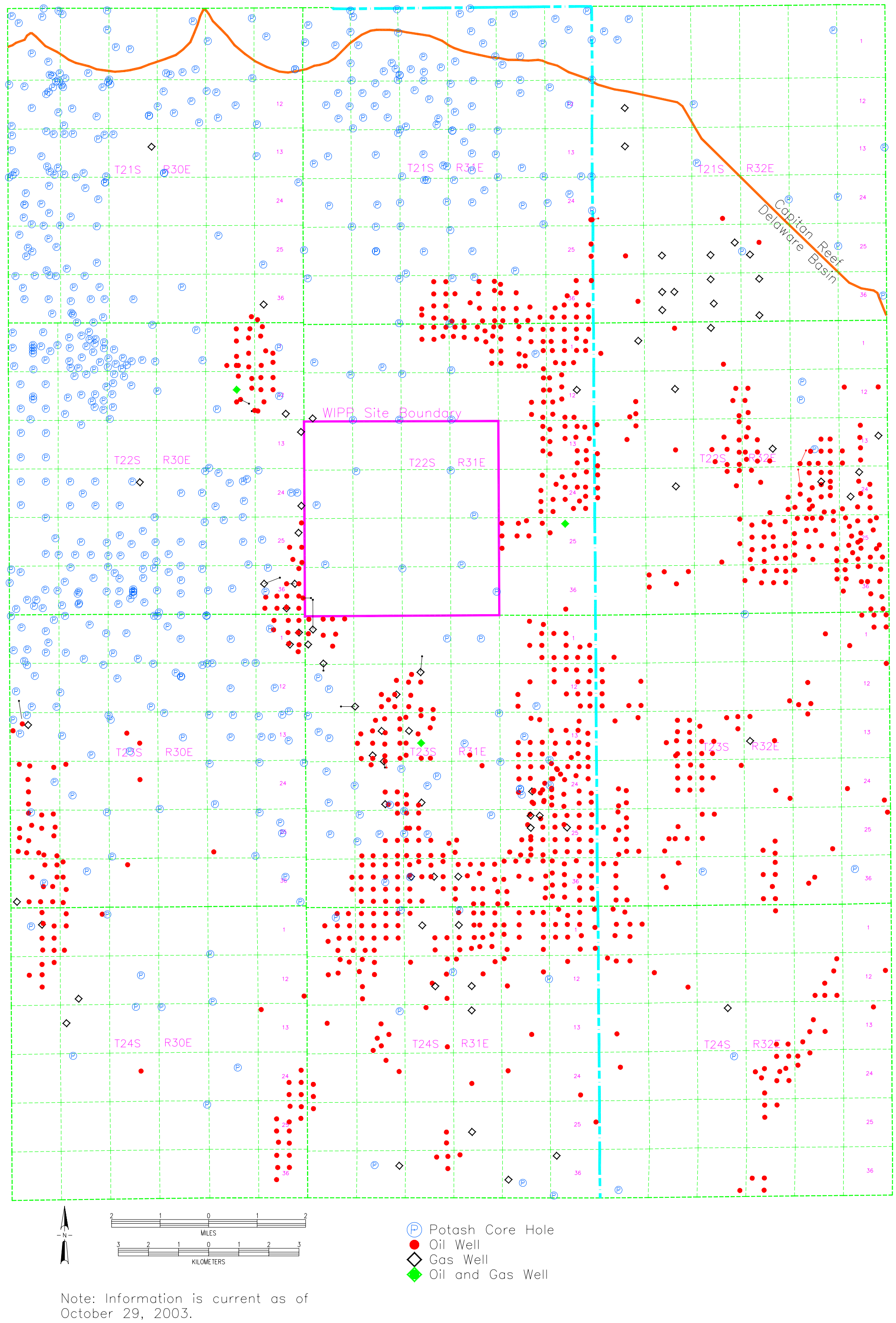

Figure 9. Petroleum and potash industry boreholes around the WIPP site. Data source: Delaware Basin Drilling Surveillance Program.

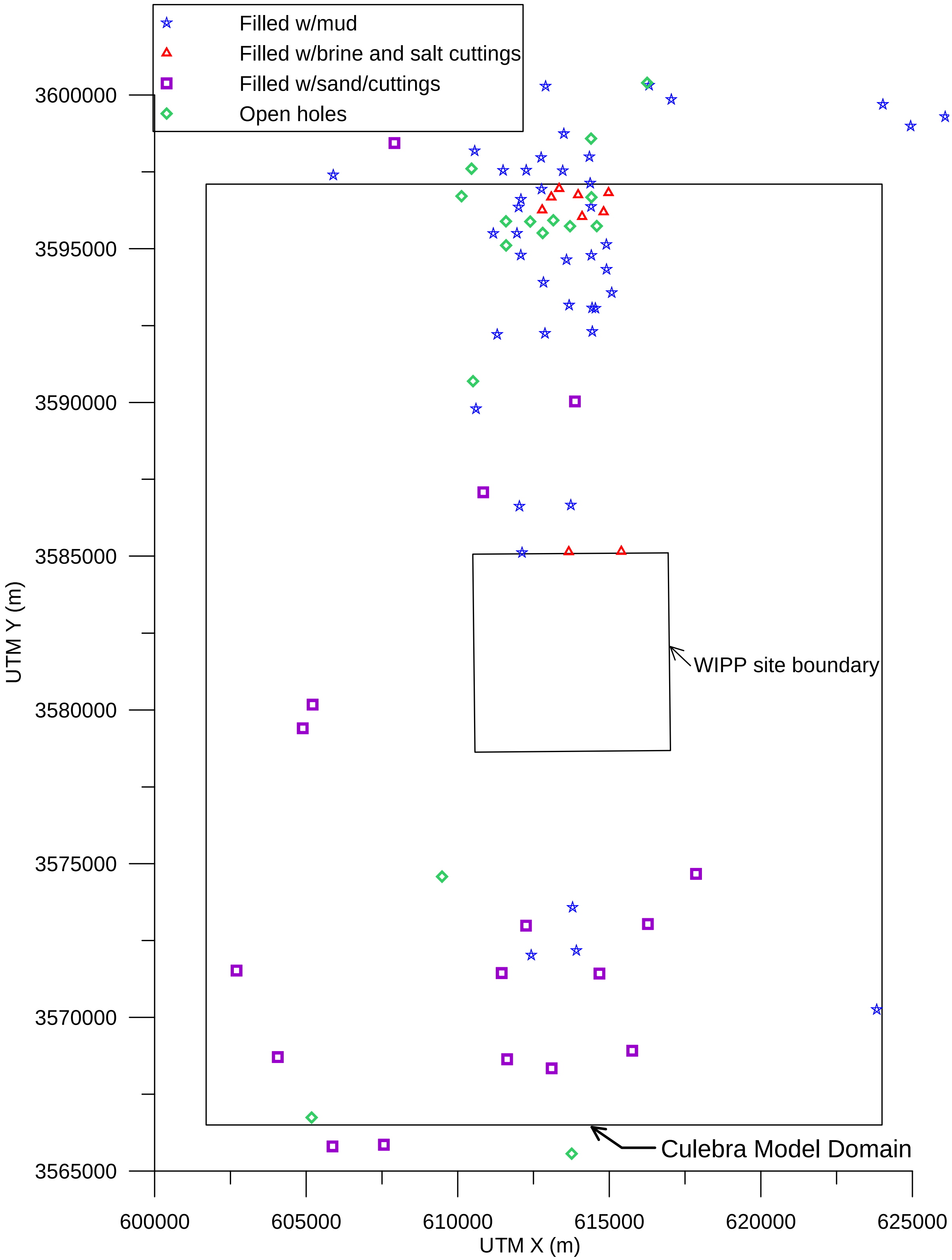

Figure 10. Potentially leaky potash holes.

Information has also been gathered on plugged and abandoned oil and gas wells from the New Mexico Oil Conservation Division (OCD) by WRES. These wells are shown on Figure 11, along with dry holes that failed to produce hydrocarbons and were plugged soon after drilling, and junked and abandoned holes, which are holes that had to be abandoned due to drilling problems. This information will be evaluated to determine if any of these wells are potentially providing conduits for vertical fluid movement.

Evaluation of plugged and abandoned boreholes also requires stratigraphic information from those locations. Much of this information has already been compiled from BLM and OCD records and from commercially available geophysical logs (Powers, 2002; 2003). Additional information can be obtained from the same sources as required.

3.4 Injection Wells

Information on injection and salt-water-disposal wells in the area surrounding the WIPP site is collected by WRES under the Delaware Basin Drilling Surveillance Program and is summarized in Kehrman (2002b). The information collected includes well locations, well-completion (e.g., casing) details, injection zones, injection pressures, and cumulative injection volumes and/or rates. Figure 11 shows the locations of the four injection wells that inject brine for secondary oil recovery and the 46 salt-water-disposal wells that inject produced brines into the Delaware Mountain Group in the 12-township area surrounding the WIPP site (T21-24S, R30-32E) that encompasses all WIPP Culebra wells (except for WIPP-29).

3.5 Groundwater Flow Model

The groundwater flow model of the Culebra developed under AP-088 (Beauheim, 2002) will be used to evaluate the scenarios potentially responsible for water-level rises. The domain for this model is shown in Figure 6. The model runs in **MODFLOW-2000**. McKenna and Hart (2003) calibrated 137 different realizations of the Culebra T field to heads measured in late 2000 (treated as "steady-state" heads) and to transient heads associated with seven pumping tests. Beauheim (2003) developed and applied acceptance criteria to identify the 100 realizations that were used for performance assessment calculations for the WIPP CRA. A subset of those 100 realizations will be used in the scenario evaluations conducted under this Analysis Plan.

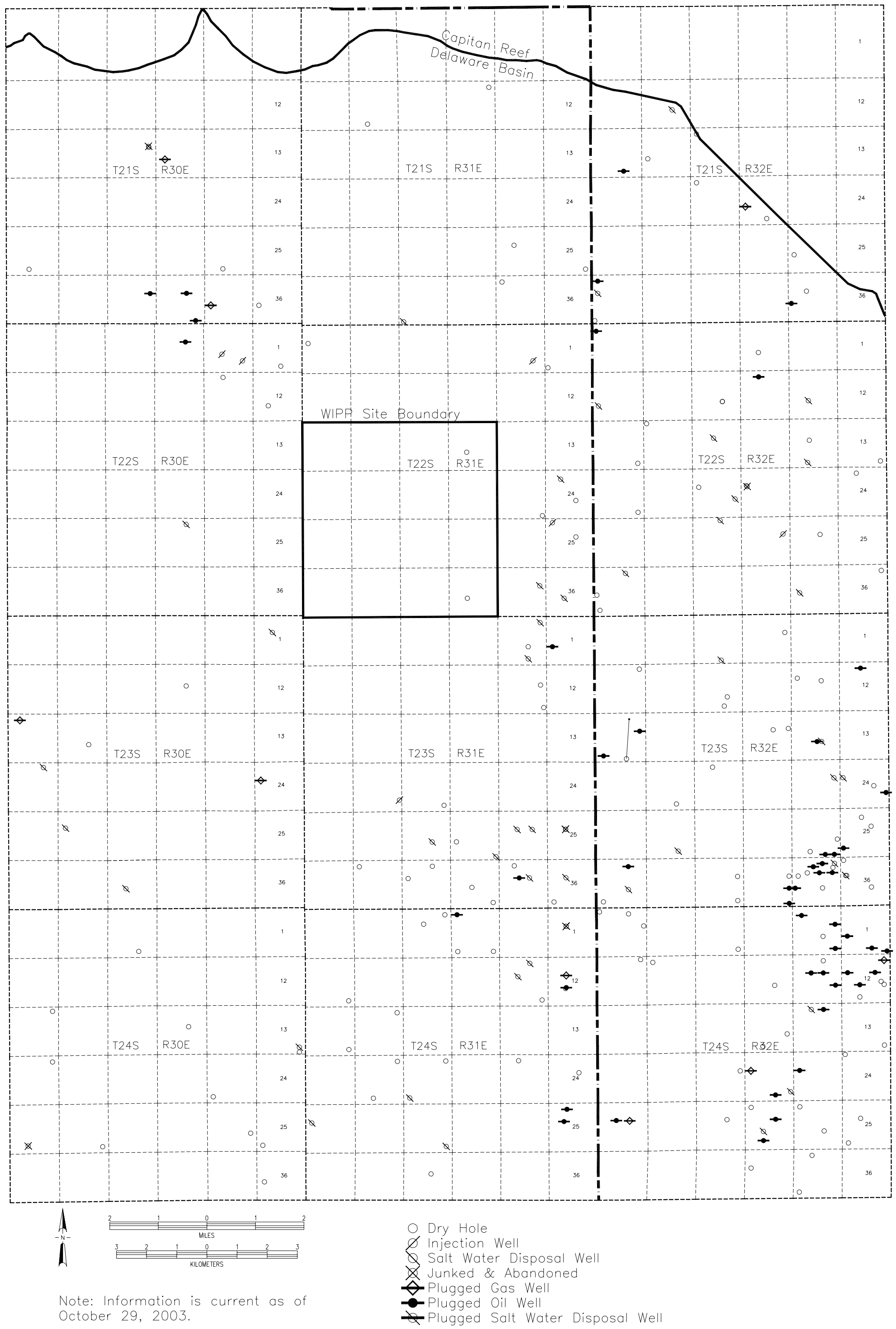

Figure 11. Plugged and abandoned, salt-water-disposal, and injection wells near WIPP. Data source: Delaware Basin Drilling Surveillance Program.

Boundary conditions used for the Culebra model consisted of constant-head boundaries on the northern, eastern, and southern extremes of the model domain, and flow lines (no-flow boundaries) down portions of Nash Draw to define the western boundary of the model (see green lines in Figure 6). The constant-head boundary values were determined by fitting a bivariate Gaussian trend surface to the late 2000 head measurements (McKenna and Hart, 2003). Because the 2000 heads presumably already reflect the sources of leakage we are trying to evaluate, some modification of the boundary heads/conditions may be necessary to perform the modeling tasks described in Section 4.

As data become available from new wells not included in the calibrations of McKenna and Hart (2003), new T fields may be developed and calibrated. Any such activity will be performed under a new Analysis Plan. The new T fields resulting from that activity, however, may be used in supplemental scenario modeling performed under this Analysis Plan.

3.6 Groundwater Chemistry

Leakage of fluids from the various sources described above would likely result in changes in groundwater chemistry in the Culebra. Culebra groundwater chemistry was evaluated at most well locations in the 1970's and 1980's by the USGS and SNL. Robinson (1997) provides a summary and evaluation of the groundwater sampling and analyses performed by the USGS and SNL. With the advent of the WIPP Water Quality Sampling Program (WQSP) in 1985, the WIPP MOC assumed responsibility for most groundwater sampling. The WQSP results are presented in Uhland and Randall (1986), Uhland et al. (1987), Randall et al. (1988), Lyon (1989), Westinghouse Electric Corporation (1991; 1992; 1995), Crawley and Nagy (1998), IT Corporation (2000), Environmental Science and Research Foundation (2001), Westinghouse TRU Solutions (2002), and Washington Regulatory and Environmental Services (2003). Samples from newly drilled and completed wells are being collected under a Test Plan by Chace (2003).

Information will also be sought from the OCD, BLM, and other sources on the chemistry of potash refining-process effluent and injection brines to assist in determining if Culebra water samples show evidence of contamination from those sources.

4. Analysis Tasks

4.1 Task 1—Data Assembly and Screening

This task entails assembling the data described in Sections 3.1 through 3.4 and 3.6 into usable databases and then screening the data as follows:

- Identify potash holes not sealed through the Culebra with cement, and units to which the Culebra might be connected.

- Identify oil and gas holes not sealed through the Culebra with cement, and units to which the Culebra might be connected.

- Identify injection wells with the most potential to be affecting water levels. Consider injection well location with respect to locations where water-level changes have been observed, the magnitude of injection, details about well completion or condition that might be pertinent to leaks, and whether or not injection was occurring in the well at the times water-level changes were observed.

- Identify wells where water chemistry may have changed over the period of sampling, and wells that might be sampled now to determine if recent changes have occurred.

The analysts for Task 1 will be Rick Beauheim (6822), Dennis Powers, and/or Bill Zelinski (6821). One or more analysis reports will be prepared describing the well-screening procedure and identifying the wells to be considered in later modeling tasks. A separate analysis report will be prepared dealing with water-chemistry issues. This task should be completed by January 2, 2004.

4.2 Task 2—Simulate Leakage from Tailings Pile

This task will involve defining a subset of the 100 CRA T field realizations to use in scenario evaluation, and then simulating various amounts of leakage into the Culebra at the Mississippi East tailings pile location for each of the selected T fields for a period from approximately 1965 through 2000. The calculated head responses will be compared to the observed changes in water levels in the WIPP monitoring network to determine: (1) what injection rates and (2) what T fields provide the closest matches between simulated and observed data. This modeling may also evaluate the possibility that water moves laterally into Nash Draw to the west of the tailings pile before moving downward into the Culebra. The simulations that most closely match the observed water-level data will be extended 100 years into the future to simulate 50 more years of additional discharge onto the tailings pile followed by 50 years of no discharge.

The analyst(s) for Task 2 will be Tom Lowry (6115) and/or Josh Stein (6852). An analysis report will be prepared describing the simulation procedure and results. This task should be completed by February 2, 2004. Portions of this task may be repeated later in 2004 after new T fields are generated incorporating data from newly drilled and tested holes.

4.3 Task 3—Simulate Leakage through Poorly Plugged and Abandoned Boreholes

This task will use the subset of T fields defined under Task 2 to simulate the effects on Culebra heads of various amounts of leakage into the Culebra through some and/or all of the plugged and abandoned boreholes identified under Task 1 as being potential leakage conduits. The calculated head responses will be compared to the observed water levels in the WIPP monitoring network to determine: (1) what leakage rates at (2) what boreholes in (3) what T fields provide the closest matches between simulated and observed data. The simulations that most closely match the observed water-level data will be extended 100 years into the future to simulate the continuing effects of leakage. Additional simulations may also be performed to assess the potential effects of similar leakage at other locations.

The analyst(s) for Task 3 will be Tom Lowry (6115), Joe Kanney (6821), and/or Josh Stein (6852). An analysis report will be prepared describing the simulation procedure and results. This task should be completed by March 1, 2004. Portions of this task may be repeated later in 2004 after new T fields are generated incorporating data from newly drilled and tested holes.

4.4 Task 4—Simulate Leakage from Injection Wells

This task will use the subset of T fields defined under Task 2 to simulate the effects on Culebra heads of various amounts of leakage into the Culebra through some and/or all of the injection boreholes identified under Task 1 as being potential leakage conduits. The calculated head responses will be compared to the observed water levels in the WIPP monitoring network to determine: (1) what injection rates at (2) what boreholes in (3) what T fields provide the closest matches between simulated and observed data. This modeling may also evaluate the possibility that an injection well may itself not be leaking, but that injected fluid is able to migrate into the Culebra through a nearby well that is not properly completed or plugged and abandoned. The simulations that most closely match the observed water-level data will be extended 100 years into the future to simulate the continued effects of leakage. Additional simulations may also be performed to assess the potential effects of similar leakage at other locations.

The analyst(s) for Task 4 will be Tom Lowry (6115), Joe Kanney (6821), and/or Josh Stein (6852). An analysis report will be prepared describing the simulation procedure and results. This task should be completed by March 1, 2004. Portions of this task may be repeated later in 2004 after new T fields are generated incorporating data from newly drilled and tested holes.

4.5 Task 5—Simulate Transport of Brine from Leakage/Injection Sources

After the combinations of T fields and leakage sources that provide the closest simulated matches to the observed head data have been identified, transport modeling will be performed to determine whether or not the hypothesized leakage is likely to have caused observable changes in water chemistry at observation well locations. A suitable transport code and modeling domain will be selected based on the specific scenario(s) to be modeled.

The analyst for Task 5 will be Joe Kanney (6821). An analysis report will be prepared describing the simulation procedure and results. This task should be completed by May 1, 2004. Portions of this task may be repeated later in 2004 after new T fields are generated incorporating data from newly drilled and tested holes.

5. Software List

The following computer codes may be used for different tasks associated with evaluation of the Culebra water-level-rise scenarios:

- ESRI ArcInfo 8.1 (off-the-shelf software);
- GSLIB v. 2.0 (acquired; routines qualified under NP 19-1);
- Mathcad 11 (off-the-shelf software);
- MODFLOW-2000 v. 1.6 (qualified under NP 19-1);
- GMS v. 4.0 (commercial; to be qualified under NP 19-1)
- PEST v. 5.5 (qualified under NP 19-1);
- STAMMT-L (qualified under NP 19-1);
- SECOTP2D (qualified under NP 19-1);
- KaleidaGraph v. 3.52 (off-the-shelf software);
- MVS v. 6 (off-the-shelf software);
- Surfer v. 8 (off-the-shelf software);
- Matlab R12.0.1 (off-the-shelf software); and
- DTRKMF (qualified under NP 19-1).

Off-the-shelf spreadsheet programs, such as Excel, and graphing programs, such as Grapher or SigmaPlot, may also be used for data manipulation and plotting. Any pre- or post-processors needed for data manipulation and transfer between codes will also be qualified as part of the analysis package.

6. Special Considerations

No special considerations have been identified.

7. Applicable Procedures

All applicable NWMP quality-assurance procedures will be followed for these analyses. Training of personnel will be done in accordance with the requirements of NP 2-1 *Qualification and Training*. Analyses will be performed and documented in accordance with the requirements of NP 9-1 *Analyses* and NP 20-2 *Scientific Notebooks*. All software used will meet the requirements of NP 19-1 *Software Requirements*. The analyses will be reviewed following NP 6-1 *Document Review Process*. All required records will be submitted to the WIPP Records Center in accordance with NP 17-1 *Records*.

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